DESIGN CONSIDERATIONS OF A FAST SWEEP OSCILLOGRAPH

by

Oscar Edward Gray, Jr.

An Essay
Submitted to the Advisory Board of
the School of Engineering,
The Johns Hopkins University
in Conformity with the Requirements for
the Degree of Master of Engineering

Baltimore
1949

TABLE OF CONTENTS

Acknowledgements

Grateful Acknowledgements are hereby made to Assistant Professor Jean V. Lebacqz PH.D., The Johns Hopkins University, whose constructive criticism and encouragement were invaluable in the development of this work, and to the Bureau of Ordnance, Navy Department, Washington, D. C., without whose aid, much of the experimental work would have been impossible.

INTRODUCTION

Coincident with the rapid development of short duration pulse techniques and the ensuing investigations in the transient and steady state wave phenomena in the ultra-high frequency and microwave spectra, the necessity for development of fast sweep oscillographs capable of displaying these phenomena has become acute.

Although several "microwave" oscillographs are in existence at the present writing, the majority of these instruments are large and heavy, and require special precautions and techniques to operate. In general, they consist of an evacuated, hollow metal chamber, its associated evacuating system, suitable control equipment, and large, high voltage power supplies for accelerating and deflection potentials. The evacuated chamber contains a hot or cold type cathode with appropriate accelerating and focusing anodes installed in one end, deflection plates installed at selected stations in the chamber, and a movable fluorescent screen placed in the other end of the chamber. The screen is viewed through a glass end window.

A typical example of the above type of oscillograph is one installed at Johns Hopkins University, Baltimore, Maryland. It consists of an evacuated metal tube.

(12 inches by 12 inches by 48 inches) containing a cold cathode type electron gun, a focusing coil, and a movable, fluorescent screen. The tube is mounted on a tubular steel framework of dimensions, 4 feet by 3 feet by 5½ feet. Within this framework are mounted the deflection power supply (10 kilovolts), the evacuating pumps, and the control equipment. A separate metal cabinet (3 feet by 3½ feet by 5 feet) houses the 70 kilovolt accelerating potential power supply. The entire installation occupies a space 9½ feet long, 3 feet wide, and 5½ feet high, and weighs approximately 4000 pounds.

One special form of the above type of instrument is a "Micro-oscillograph"[1] designed by Gordon Lee. In lieu of a fluorescent screen, microfilm is placed in a holder inside the vacuum chamber and exposed directly by the small intense electron beam. Extremely small deflections of the electron beam have been recorded in this manner. Frequencies in the order of 10,000 megacycles have been recorded by this method. The electron optics employed in this instrument are similar to those in the RCA Electron Microscope.[2] In appearance and size, it closely resembles the latter instrument.

The "Fast-Sweep Synchroscope",[3] developed at the Radiation Laboratory, Massachusetts Institute of Technology, is a notable departure from the general

class of oscillographs mentioned above. It employs a special 5RPA type cathode ray tube (developed by the Allen B. DuMont Laboratories, Inc.) operating at a total accelerating potential of 30 kilovolts and deflecting potentials of 1.2 kilovolts. The linear deflecting potentials are derived from the discharge of an artificial pulse line through a linearizing network. A hydrogen thyratron is employed as a switch to charge and discharge the line. Because of time variations in the ionization and deionization potentials of the thyratron, the maximum usable sweep speed was limited to about 75 inches per microsecond. One model of this instrument, complete with power supplies, is housed in a metal cabinet of dimensions 3 feet wide, 3 feet deep, and 4 feet high. Despite its sweep speed limitations, its development represented a major accomplishment in the reduction of size and weight of high speed oscillographs.

The purposes of this essay are:

1) To present some general considerations in the possible design of light, compact, high speed oscillographs.

2) To present a basic principle of deriving fast sweep potentials which heretofore has been unexploited.

3) To present a complete oscillograph design based on this principle capable of linear sweep speeds of 100 to 400 inches per microsecond.

PART I. GENERAL DESIGN CONSIDERATIONS

Any electronic oscillograph may be classified as an instrument composed of the following systems:

1) The Display System

This group of circuits and devices provides a conversion from electrical energy to light energy for visual or photographic recording, and controls the position, average intensity, and resolution of the visual display.

2) The Sweep System

This group of circuits defines the nature and character of the cathode ray tube display. It generates suitable waveforms, which when impressed on the deflection plates of the cathode ray tube, deflect the beam in accordance with a given function of time.

3) The Intensifier

This group of circuits governs the brilliance or light level of the CRT display. It provides proper waveforms, which, when applied to the grid or cathode of the cathode ray tube, cause increased brilliance or a higher fluorescent light level during the sweep period.

4) <u>The Time Base</u>

This group of circuits defines and controls the time sequence of circuit operations. It provides appropriate waveforms to initiate action of the other component systems in proper time sequence.

5) <u>The Signal Channel</u>

This group of circuits controls the amplitude of the waveform under observation. It amplifies or attenuates the input signal waveform with a minimum change in wave shape and applies it to the deflection plates of the Cathode Ray Tube.

6) <u>The Power Supply</u>

This group of circuits converts the normal 110 volt, 60 cps., alternating current power source into appropriate direct and alternating current potentials necessary for the operation of the various component circuits.

7) <u>Auxiliary Systems</u>

This group of circuits provides calibrating waveforms for amplitude, frequency, and time measurements, provides means for the application of two or more waveforms on the same display, etc., to extend the utility of the instrument for specialized purposes.

General design considerations of the component

systems are as follows:

1. The Display System

The devices and circuits in this group are:

1) The cathode ray tube.

2) Horizontal centering controls.

3) Vertical centering controls.

4) Focus control.

5) Average Intensity controls.

Since, this discussion is restricted to possible light, compact designs, the possibility of employing heavy, metal cathode ray tubes is eliminated. With this restriction, the designer is immediately confronted with the problem of selecting a standard cathode ray tube capable of displaying phemonena with writing rates[4] in excess of 100 inches per microsecond.

The only commercial cathode ray tube capable of writing rates in this range is the DuMont type 5RPA. Experimental data on this tube indicate that it is capable of displaying single transients with writing speeds in excess of 400 inches per microsecond.

The general characteristics[5] of the 5RPA series are:

Electrical

Heater Voltage		6.3 volts
Heater Current		0.6 amp.
Focusing Method		Electrostatic
Deflecting Method		Electrostatic
Screen Phosphor	P2	P11
Fluorescence	Green	Blue
Phosphorescence	Green	----
Persistence	Long	Short

<u>Maximum Design Center Ratings</u>

Anode #3		25.5 Kilovolts DC
Anode #2		3.5 Kilovolts DC
Anode #1		1.55 Kilovolts DC
Grid #1	Negative	-125 volts DC
	Positive	0 volts DC

Max. Voltage Anode #2 to deflection plates 1200 volts peak

Deflection Factors for Anode #3 voltage of 20 KV and Anode #2 voltage of 2 KV.

D1-D2 140 to 210 DC Volts per inch

D3-D4 131 to 197 DC Volts per inch

Mechanical

Overall length	16.75 inches
Diameter of bulb	5.25 inches
Minimum useful screen diameter	4.25 inches

For general laboratory purposes, the type P2 screen is recommended[6] since the screen has a dual characteristic; a short-persistence fluorescence, and a long-persistence phosphorescence. By use of suitable filters, either characteristic may be accentuated. This screen also possesses a slightly higher limit writing rate than the P11 screen; a distinct advantage when operating at high sweep speeds at low repetition rates.

No data is available on the limit writing speeds of this type tube under repetitive types of excitation. It is to be anticipated, however, that the writing speed will increase with an increase in repetition rate since the average power input to the screen will increase also with an increase in repetition rate. This would be advantageous in the observation of pulse trains and high frequency sine waves.

Conventional methods of obtaining centering voltages from the low voltage, direct current power supply may be employed. Care must be exercised, however, in providing adequate decoupling between the power supply leads and the deflection plates since high frequency voltages will be impressed on the plates. Radio frequency

chokes, and/or resistors, by pass capacitors should be sufficient for this purpose.

The Focus control and intensity control may be portions of the "bleeder" resistance in the accelerating potential power supply. Potentiometers possessing a dissipation rating of one watt are usually adequate for this purpose. There is one mandatory precaution that must be observed if this method is used. Since Anode #2 of the cathode ray tube is usually maintained at ground potential, the focus and intensity controls will be at large negative potentials with respect to ground.

Adequate insulation with respect to ground must be provided in the mountings of these potentiometers and either insulating shafts, or insulated flexible couplings employed to protect the operator from these high voltages.

2. The Sweep System

In the design of any oscillograph, the sweep system circuits are of predominant importance since they determine the character of the cathode ray tube display. They may be classified as to the type of beam deflection they produce.

1) Linear $x = kt$

2) Exponential $x = Ae^{-\alpha t}$ $x = A(1-e^{-\alpha t})$

3) Sinusoidal $x = A \sin kt$ or $A \cos kt$

4) Others $x = kt^2$ (parabola)

$x = \sqrt{t^2 - t_h^2}$ (hyperbola)

where x = the instanteous horizontal position of the beam spot. It is assumed that the sweep is applied to the horizontal deflecting plates.

t = time

k = a constant

A = Amplitude constant

For general laboratory purposes, it is essential that the sweep presentation of the waveform under observation be either readily and easily calibrated, or easily calculated from visual observations of the display. This fact immediately places a restriction of the selection of the sweep system circuits to those which generate known simple functional waveforms such as types 1, 2, and 3 above. Obviously, the most simple and the most convenient sweep is the linear type and it is the type this discussion will consider.

The degree of perfection of the linearity of the sweep voltage may be expressed in two ways,

1) Displacement error; the deviation of the instantaneous voltage of the actual sweep from the instantaneous voltage of a straight line which closely represents the actual sweep expressed as a percentage of the actual sweep amplitude.

2) Slope error; the deviation of the instantaneous slope of the actual sweep from the slope of the assumed straight line expressed as a percentage of the slope of the assumed straight line.

Several types of circuits exist for approximating a linear voltage waveform.[7] In general, they operate on an exponential voltage waveform ($e = E_{max}(1-e^{-\alpha t})$, by various methode to produce an approximate linear rise or fall in voltage. The most common of these is either charging or discharging a capacitor:

1) From a constant voltage source through a resistor.

2) From a constant voltage source through a high variational impedance of low DC resistance.

3) With circuits involving positive and negative feedback.

4) With circuits involving negative feedback.

Circuits employing the principles above have been designed to produce linear sweeps with displacement errors of 0.01 percent for small amplitude sweeps (100-200 volts max.). While such circuits are useful for comparator and time delay purposes, displacement errors of 1 or 2 percent are visually undetectable on the screen of a cathode ray tube. For example; a 2 percent error in a 100 volt per 1 inch sweep would be 0.020 inches. Since the diameter of the visible spot on a cathode ray tube is of comparable magnitude, the linearity error is blanked by the uncertainty error in position as defined by the spot.

One source of fast sweep speeds that has received little attention to date is the sinusoidal waveform. The portion of a 1200 volt peak amplitude sine wave at the x axis intercept consisting of 39 degrees of the total period of 360 degrees is approximately a straight line. It has a maximum displacement error from a straight line through the 400 volt points and the x axis intercept, of 2 volts, or 0.25

The Sine Wave Approximation of a Linear Function

	Sine Wave	Straight Line
Equation:	$e = E \sin x$	$e = mx$
Slope:	$\frac{de}{dx} = E \cos x$	$\frac{de}{dx} = m$

Since we are considering only the portion of the sine wave where $0 < \sin x < .333;\ 1 > \cos x > .944.$

$$e = \frac{E}{3},\ \text{then } m = \frac{E}{3x} = \frac{E}{\frac{3\pi}{180^\circ} \times 19.55^\circ} = .976E$$

Displacement Error

X (degrees)	E sin X	mx	error	% error
19.55	.333 E	.333 E	0	0
15	.259 E	.262 E	.003	.3
10	.1735 E	.1745 E	.001	.1
5	.087 E	.0873 E	.0003	.03
0	.000	.000	.000	0

Slope Error

19.55	$\phi = \tan^{-1}$ .944 E	$\phi = \tan^{-1}$ .976 E
15	" = " .965 E	" = " "
10	" = " .985 E	" = " "
5	" = " .996 E	" = " "
0	" = " E	" = " "

For $E > 10v$; error $< 0.2^\circ$ or $< .25\%$

percent of the total amplitude of the sweep or a displacement error of 0.125 percent with the median straight line through the x axis intercept. The slope error of the same sine wave is less than 5 minutes of arc or less than 0.09 percent of the straight line slope.

We see that by utilizing 39 degrees of the 360 degree period of a 16 megacycle sine wave, an 800 volt per 0.007 μs sweep voltage with a displacement error of only 0.25% and a slope error of less than 0.09% is produced. Applied to the DI-D2 trace deflection plates of a 5RP2A (deflection constant of approximately 200 volts/in.) type cathode ray tube, this waveform, would provide an excellent linear sweep of 4 inches, or effectively, a linear sweep time base of 1.25 X 10^{-9} seconds per inch.

Several advantages of the sine wave sweep system over the linearized exponential sweep system are:

1) The fast waveforms required are easily generated by a crystal oscillator and frequency multipliers for any sweep speed.

2) Sweep voltage peak amplitudes of four times the DC plate voltage are easily

obtainable.

3) Stray capacitances which limit the speed of transient type systems have reduced effect except to limit upper sweep frequencies to about 200 mc.

4) No switch devices are needed to charge and discharge sweep capacitors hence one of the major sources of "jitter" is eliminated.

5) Good inherent long time stability since a crystal oscillator may be used as timing standard.

6) No special critical circuits are needed to realize the principles physically.

7) Relatively low power input is required to obtain fast sweep speeds.

8) Amplifier bandpass problems are eliminated since the sweep circuits operate at single frequencies.

9) High amplifier gains are realized through the use of single frequencies and tuned circuits.

10) The system lends itself readily to accurate trigger phasing through the use of sine wave phase shifting circuits.

Two major disadvantages to the system are that:

1) The repetition rate of the sweep voltage is f, where f is the frequency of sweep wave (in above example; 16 million times per second) requiring the use of a sweep selection system to reduce the repetition rate to a usable figure.

2) The requirements on the cathode ray tube beam gate voltage are severe.

a) It must be of duration 1/9 of the sweep period (in above example 0.007 microseconds).

b) It must possess extremely fast rise times.

In order to employ a sine wave sweep system in an oscillograph, the two major disadvantages must be either eliminated or, at least, minimized. Fortunately, these disadvantages are subject to easy solution by means of a gate selection system illustrated in Figure I-1.

The operation of the system shown in (a) may be described as follows: An oscillator generates a continuous chain of sine waves which is multiplied to the proper frequency for the selected sweep speed. This chain is impressed on a passive network of resistors, capacitors and/or

GATE SELECTION SYSTEMS

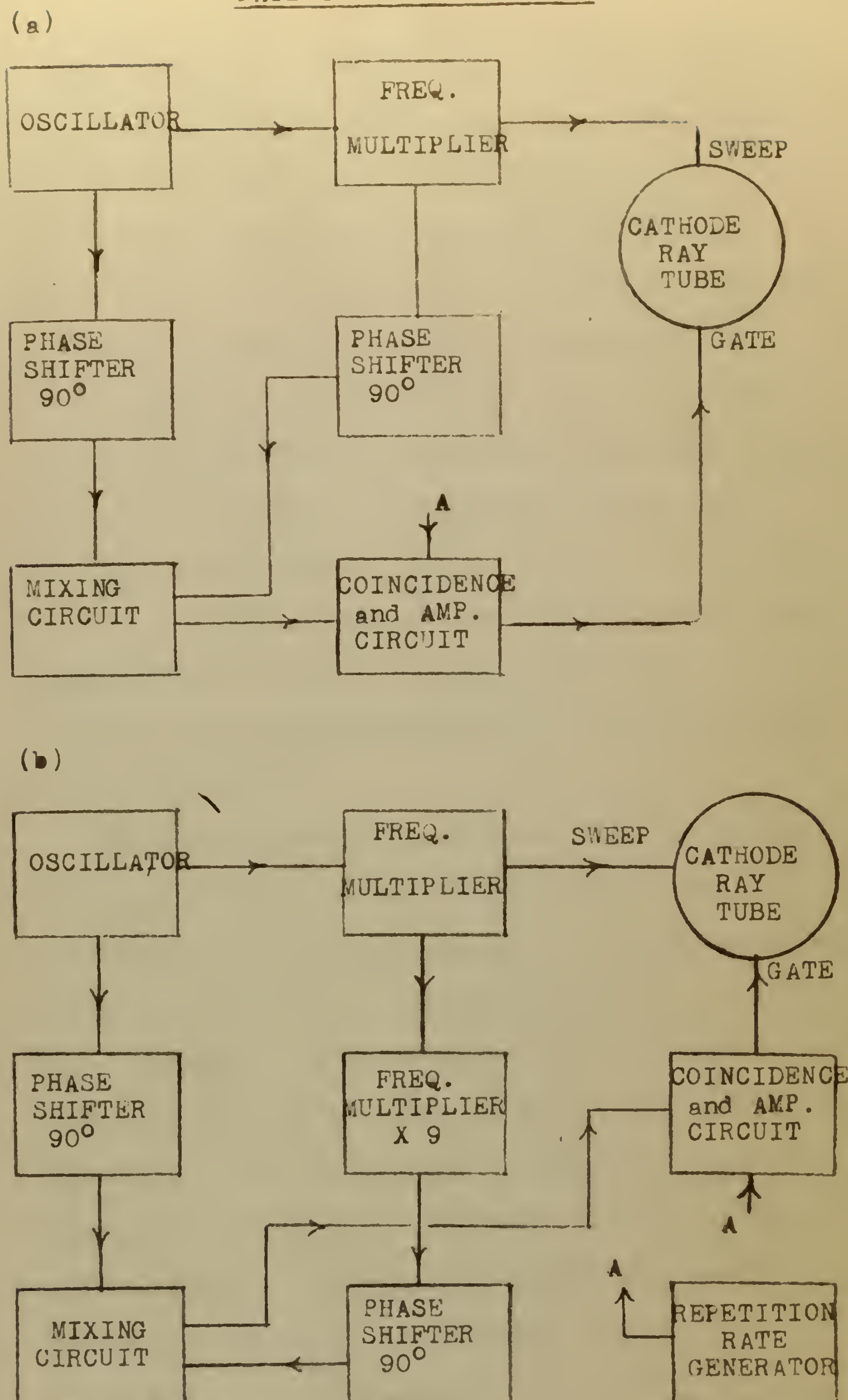


FIGURE I-1

inductances to provide a fixed shift in the sine waves of one-fourth cycle. The sine wave peaks in this shifted chain coincide with the rise or fall of voltage in the original wave train.

A repetition-rate generator produces a square selector pulse which, when introduced into a "coincidence" circuit, selects one of the half-waves of the shifted, sine wave train. The selected half-sine wave is limited and amplified to produce a rectangular pulse to act as an intensifier waveform. The resultant cathode ray tube display is a line representing the portion of the sine wave illuminated by the duration of the intensifier pulse.

The operation of the system in (b) is identical with that above with the exception that in lieu of the half-sine wave of the sweep frequency being utilized as an intensifier pulse, a half-sine wave of a frequency nine times greater is employed. This provides a gate pulse of duration one-ninth the total period of one cycle of the sweep wave. This type of system would be suitable for use for illuminating 39.5 degrees of the sine wave cycle as proposed above.

3. <u>The Intensifier</u>

The circuits in this system generate a pulse which, when placed on the grid (positive pulse) or on the cathode (negative pulse) raises the negative grid bias voltage on the cathode ray tube to a value where large beam currents flow in the tube. This action causes greater light energy output from the fluorescent screen of the cathode ray tube during the application of the pulse.

It is mandatory that the gate pulse have substantially the following characteristics;

1) Possess a rectangular form with fast rise and decay times.

2) Have a duration equal to the sweep cycle.

3) Be coincident with the sweep waveform to prevent the sweep line from shifting on the screen of the cathode ray tube.

4) Possess sufficient amplitude to produce the desired brilliance at the screen.

To satisfy the above requirements, the gate pulse is usually derived from some stage in the sweep system. For triangular waveform sweeps, the sweep voltage waveform may be differentiated to form a rectangular gate pulse, or the negative

square pulse used to initiate the sweep generator may be used. In sinusoidal sweep systems, either the sweep wave or one of its harmonics may be phase shifted and shaped to provide a suitable gate for any portion of the wave desired (See Figure I-1).

The triangular sweep waveform intensifying methods are illustrated in Figure 1-2. In (a), the triangular sweep is applied to a capacitor-resistor differentiating network. The output waveform of this network is substantially a rectangle. This rectangular pulse is applied to the grid of the cathode ray tube as an intensifier pulse. In (b), the negative sweep trigger rectangle is impressed on the cathode of the cathode ray tube through a separate channel as illustrated.

4. <u>The Time Base</u>

Since this group of circuits determines the proper time initiation of the other component system, it is the most important single group in the oscillograph. The rigid and severe requirements to be satisfied by the time standard, as established by this system are;

1) It must possess good inherent short-time

TRIANGULAR WAVEFORM INTENSIFIERS

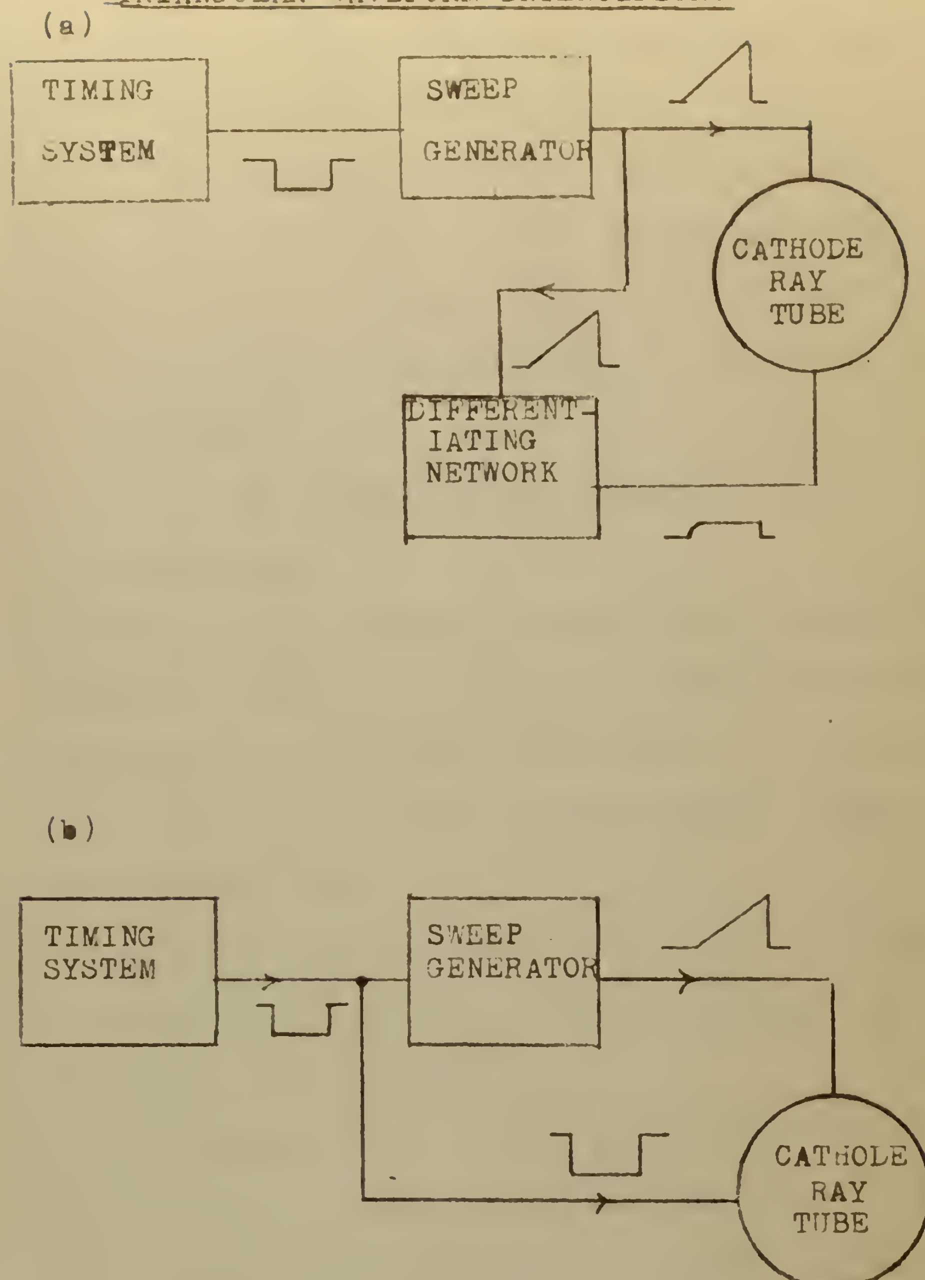


FIGURE I-2

and long-time stability.

2) It must be relatively insensitive to:

a) Temperature changes.

b) Variations in tube characteristics.

c) Variations in power supply voltages.

3) It must possess excellent waveform of types necessary to ensure proper initiation of other circuits.

4) It should require a minimum of circuits and adjustments.

Fortunately, sinusoidal oscillators employing a quartz crystal as the frequency determining element virtually satisfy the requirements on this system. The characteristics of certain forms of these oscillators are;

1) They possess frequency stability of two parts per million per hour and 0.5 parts per million over a long period.

2) With certain type crystals (GT cut), they are relatively insensitive to temperature changes.

3) They produce excellent sinusoidal waveforms which may be utilized directly for sinusoidal circuit initiation, or shaped to provide accurate pulses for pulse circuit initiation.

4) They require a maximum of two tubes in their

more complex forms (bridge-stabilized oscillator) and reouire, normally, no adjustment. (Some frequency standards (100 KC) have a fine frequency adjustment)

Unfortunately, the sinusoidal waveform generated by a crystal oscillator poses a problem for the designer. Linear circuit elements do not change the shape of this type waveform, affecting only its amplitude, and phase. Hence, to generate other waveforms, such as a rectangular pulse, from the sinusoid, requires the use of non-linear circuit elements such as contact crystals or vacuum tubes. The broken-line characteristics of such elements are not perfect, however, and the definition of the break is not precise. This lack of precision causes some uncertainty in the time position of the leading edge of the rectangular or other waveform. Although this effect may be reduced to a minumum bv fast transition of the input waveform through this retion, it is a very definite source of random time variation in the timing system. Although the above discussion is perfectly valid for all vacuum tube circuits employing grid cut-off points and plate current saturation points as a wave shaping artifice, it is particularly important in a time standard system.

To utilize the precision time standard as obtained by an appropriate crystal oscillator, some method of multiplying or dividing its frequency, or of synchronizing its waveform with a separate repetition-rate generator must be employed. This is made necessary by the fact that a crystal will oscillate predominantly at one frequency determined by its dimensions and the fact that several different frequencies or repetition rates may be necessary to time operations in a given oscillograph.

Sinusoidal frequency multiplication may be obtained by Class C type amplifiers which generate a large number of harmonics of the input frequency. A tuned-circuit is utilized to filter the desired harmonic from the multi-frequency current pulse in the plate circuit of the amplifier. These multiplier amplifiers are subject to two serious deficiencies;

1) High Q tuned circuits are mandatory for good rejection of unwanted harmonics.

2) Large phase shifts occur in the output harmonic with a small shift of either the input frequency or the high Q tuned resonant circuit in the plate circuit.

A compromise between harmonic rejection and phase stability is required since these two desirable

characteristics require opposite solutions.[8]

Sinusoidal frequency division is difficult although several solutions have been proposed. The most successful of these solutions are circuits involving regeneration and modulation. The frequencies at which these latter type circuits can operate is limited only by the frequency range over which amplifiers, modulation and frecuency multipliers can be built.[9]

Methods of synchronizing continuous, sinusoidal waveforms with either a random pulse or a separate repetition rate generator are many and varied. In general, they consist of circuits, by which, one or more of the continuous sinusoidal waveforms is selected by a "coincidence" tube actuated by a selector pulse derived from the repetition rate generator. One such system is described in Part II of this essay.

The author proposes the use of a stable crystal oscillator with suitable multipliers, combined with a multiple time scale selection method furnished by the synchronizing techniques outlined above to obtain an accurate time base system for fast sweep oscillographs.

5. The Signal Channel

Unfortunately, the high resolution of a fast sweep oscillograph places stringent requirements on any amplifiers for use in this system. Amplifier design

principles[10] indicate that the band-pass necessary for proper response at sweep speeds of 100-400 inches per microsecond is 1000 megacycles or more. No amplifiers exist at the present time capable of pass bands approaching this requirement.

For lack of a suitalbe amplifier, the input signal is applied directly to the deflection plates of the cathode ray tube. Unfortunately, this recuires the input signal to have sufficient amplitude to overcome the low deflection constant of the cathode ray tube. For the 5RP2A type tube, this constant is approximately 200 volts per inch deflection.

6. <u>The Power Supply</u>

Since there are many thorough treatments on the design of direct current power supplies in the prevailing literature, the author deems it redundant to restate elements of these treatments.

However, the following general considerations in the design of power supplies for a fast sweep oscillograph are dictated by experience:

1) Electronically-regulated direct current supplies should be utilized on the low voltage circuits to minimize voltage variations. This precaution will ensure more reliable operation of these circuits.

2) Where power line fluctuations are large, the employment of constant voltage transformers to stabilize the line voltage is recommended. This is particularly desirable in order to avoid tube heater voltage variations.

3) The employment of the new television radio frequency and pulse type, high voltage supplies for cathode ray tube acceleration voltages permits a great reduction in the size and the weight of this supply.

4) The direct current plate connections to circuits containing fast transition circuits such as blocking oscillators, multivibrators, etc., should be provided with decoupling networks to prevent undesirable coupling through the power leads to other circuits. Likewise, the leads to circuits containing radio frequencies should be well by-passed to ground and should contain radio frequency choke coils.

7. <u>Auxiliary System</u>

In general, this system may contain the following possible circuits.

1) An oscillator which generates a sinusoidal waveform of calibrated frequency, and calibrated amplitude. This waveform is applied to the

vertical deflecting plate to enable the operator to mark known intervals of time and/or voltage on the screen of the cathode ray tube.

2) A multivibrator switch circuit which alternately applies two or more input signals to the signal channel for coincident display on the screen of the cathode ray tube.

3) Special signal generators, such as television signal generators, square wave generators, etc..

Since the number and type of auxiliary circuits employed in a oscillograph depends on the specialized applications of the instruments, and there exists adequate discussions of these types of auxiliary circuits in the prevailing literature, the author deems it superfluous to include such discussions in this essay.

One precaution must be observed in the use of any auxiliary system, and that is, the system must possess characteristics of stability, band pass, and accuracy commensurate with the degree of resolution of the oscillograph.

PART II. A PRACTICAL HIGH SPEED OSCILLOGRAPH DESIGN

With the foregoing general considerations in mind, the author proposes the following design of a possible light, compact, fast sweep oscillograph. The following arbitrary requirements were established to provide a basis for the design.

1) The sweep system must be capable of speeds in the 100 to 400 inches per microsecond region.

2) The time base must be reasonably accurate and maintain excellent stability over long periods of time.

3) The instrument must be capable of generating an accurate trigger pulse with an absolute minimum of time variation in repetition rate.

4) The circuits must be capable of accepting a trigger pulse from external equipment without extraneous disturbances in the operation of the system.

5) The system must have an absolute minimum of time variation between trigger pulses and sweep pulses.

6) The display must afford visual observation of signals and phenomena (both transient and steady state) of time duration in the milli-microsecond region.

7) The unit should be reasonably simple (within the requirements stated above), relatively light and reasonably compact in structure.

8) The system should require a minimum of external adjustments and calibration, and such necessary adjustments should be non-critical.

To satisfy the above requirements, the following systems were selected as component parts of the design:

1) The display system to consist of a DuMont type 5RP2A cathode ray tube operating at a total accelerating potential of 30 kilovolts, with conventional centering, intensity, and focus controls.

2) A sinusoidal sweep system to consist of a crystal oscillator operating at one megacycle per second, four frequency multipliers and one amplifier to provide a linear sweep of 270 inches per microsecond and a 16 megacycle gate pulse.

3) The intensifier to consist of a two stage gate amplifier. This amplifier shapes a positive 16 megacycle half sine wave to a positive rectangular gate pulse for application to the grid of the 5RP2A cathode ray tube.

4) The time base to consist of a multiple-scale pulse selection system to synchronize a variable repetition rate multivibrator to the one megacycle

crystal oscillator. This is to provide sweep gates and output triggers directly from the one megacycle crystal sweep timing circuits.

5) The signal channel to consist only of direct connections to the deflection plates.

6) The power supply to consist of a conventional 300 volt 350 ma. D.C. power supply, a conventional, variable 300-700 volt, 200 ma. D.C. power supply, a conventional, -100 volt bias supply and a variable, (20 to 35 KV, 2 ma) radio frequency, high voltage supply for accelerating potentials.

7) No auxiliary systems to be employed on experimental model.

The synthesis of the basic design is illustrated in Figure II-1, with respect to the required individual component circuits. With reference to Figure II-1, the following specific circuit design consideration were employed in an experimental model of the oscillograph.

1. <u>The Crystal Oscillator</u>

The 1 megacycle crystal oscillator is of a special design[11] recommended for use with the Bliley SMC-100 type crystal. From data furnished with the crystal, it is estimated that the maximum drift (long time) will be in the order of 0.001 percent. It is expected that this

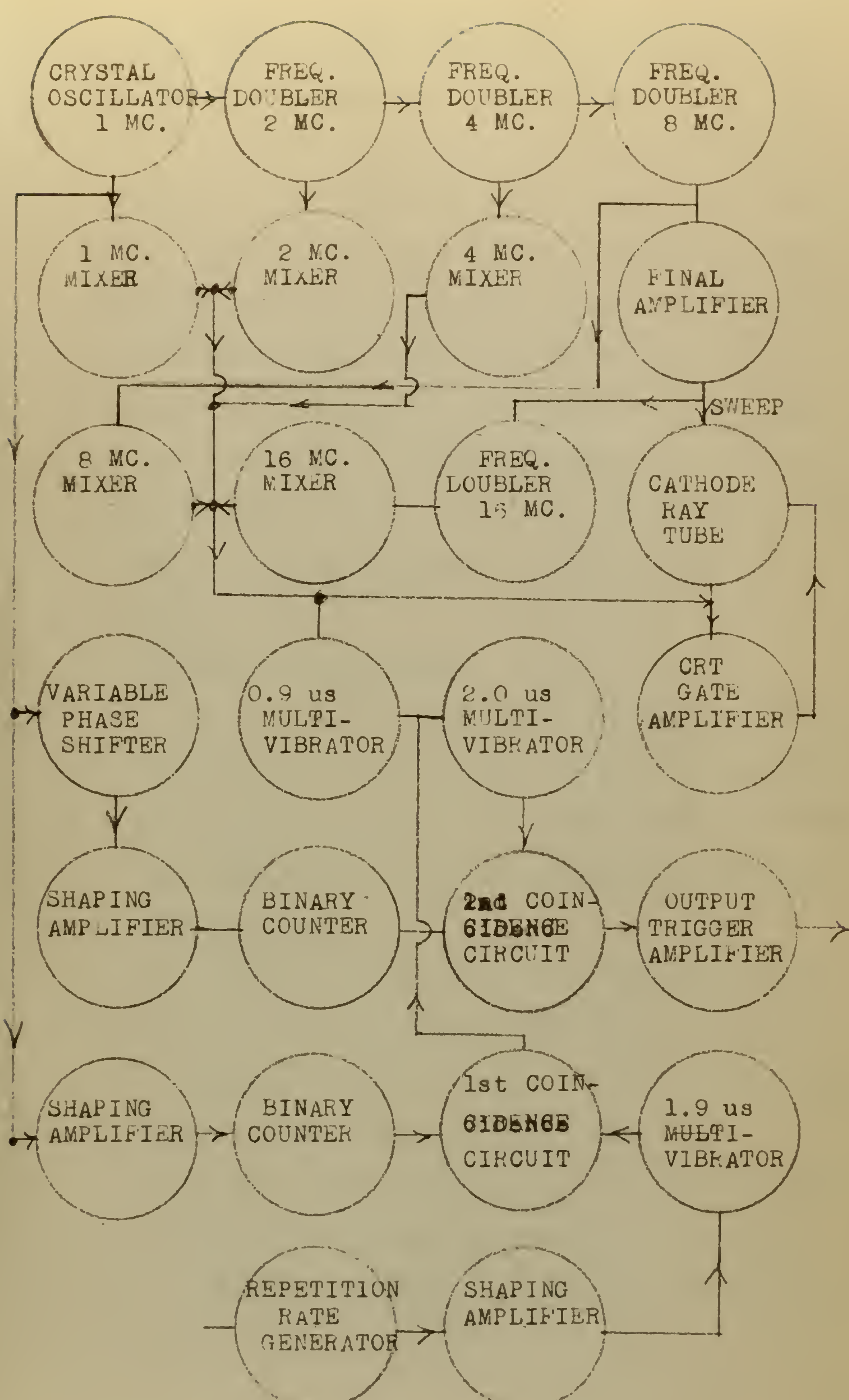

CRYSTAL OSCILLATOR 1 MC.
FREQ. DOUBLER 2 MC.
FREQ. DOUBLER 4 MC.
FREQ. DOUBLER 8 MC.
1 MC. MIXER
2 MC. MIXER
4 MC. MIXER
FINAL AMPLIFIER
SWEEP
8 MC. MIXER
16 MC. MIXER
FREQ. DOUBLER 16 MC.
CATHODE RAY TUBE
VARIABLE PHASE SHIFTER
0.9 us MULTI-VIBRATOR
2.0 us MULTI-VIBRATOR
CRT GATE AMPLIFIER
SHAPING AMPLIFIER
BINARY COUNTER
2nd COIN-CIDENCE CIRCUIT
OUTPUT TRIGGER AMPLIFIER
SHAPING AMPLIFIER
BINARY COUNTER
1st COIN-CIDENCE CIRCUIT
1.9 us MULTI-VIBRATOR
REPETITION RATE GENERATOR
SHAPING AMPLIFIER

FIGURE II-1

magnitude of stability will be sufficient for the sweep system.

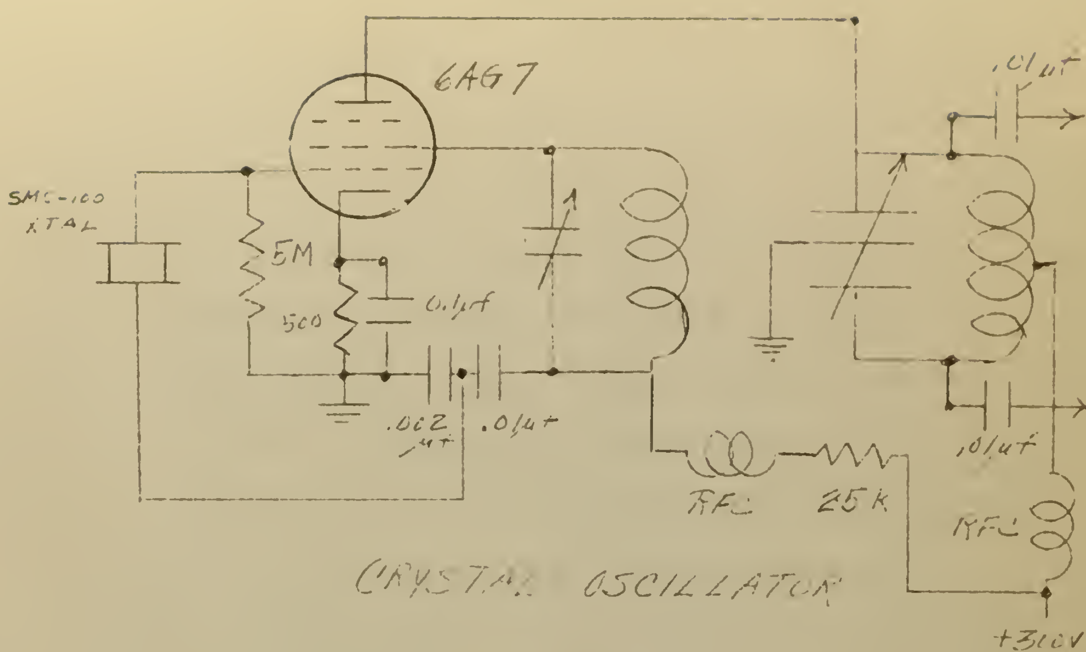
Stability considerations of oscillators[12] indicate that for the sweep timing generator, a bridge-stabilized crystal oscillator[13] with temperature compensation would be preferable to the above type. Stability in the order of one part per 10^9 has been achieved with this circuit. However, to attain simplicity in the experimental design, the Bliley circuit is utilized. The circuit diagram is illustrated in Figure II-2.

2. Frequency Multipliers

The frequency doublers in the sweep system are designed specifically for excellent harmonic selection with good phase stability. To achieve this compromise, the following design features are employed.

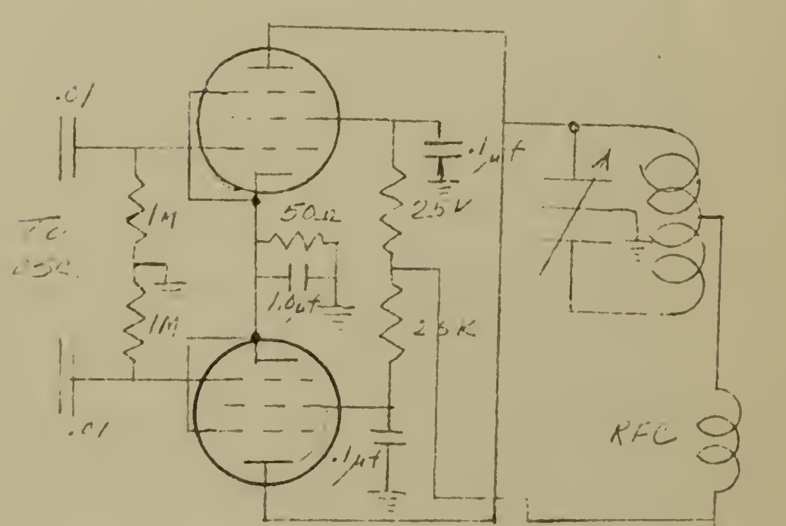
1) Pentode type tubes were selected because of their high power sensitivity. Less grid driving power is required for a given degree of output with this type tube.

2) The "push-push" type of circuit is used. The plate current pulses in this type of circuit contains only the even harmonics of



CRYSTAL OSCILLATOR

FIGURE II-2



2 mc FREQUENCY DOUBLER

FIGURE II-3

the input freouency therefore practical rejection of the odd harmonics is achieved.

3) The grid bias is chosen so that plate current flows over approximately 130 degrees of the fundamental frequency with an input signal of 50 volts peak amplitude. This selection provides an average 2nd harmonic content to 4th harmonic content ratio of approximately 8.7.[14]

4) With an estimated loaded circuit Q of 12, a phase shift of 0.2 degrees was calculated for a 0.01 percent change in input freouency.

5) Careful layout of the circuit was employed so that the tuned circuits are not exposed to heat dissipated by tubes, and resistors. The circuit diagram is illustrated in Figure II-3.

3. <u>The Final Amplifier</u>

The final, Class C, radio frequency amplifier is of conventional design[15] and requires no special comment.

4. <u>The One Megacycle Amplifiers</u>

The one megacycle amplifiers are of conventional design. They are provided with proper grid bias to limit the peaks of the sine wave to form a square wave. Their sole purpose is to provide a proper trigger for the binary counter.

5. The Binary Counters

They are conventional bistable "flip-flop" circuits[16] and are the same design as employed in the RCA Electronic Counters.

6. The Pulse Shaping Amplifier

This amplifier is a typical 2 stage circuit designed to amplify, differentiate, and peak an input waveform.

It is used to form a sharp trigger for the 1st selector pulse multivibrator from the 50 μs rectangular pulse supplied by the repetition rate multivibrator. It fulfills a secondary purpose in providing an isolation stage between the two multivibrators.

7. The Repetition Rate Multivibrator

The design of this circuit follows current practice. A switch arrangement converts the normal astable (free-running) condition to a monostable (one-shot) condition to accept a pulse from external sources.

It generates a rectangular pulse of 50 micro-seconds duration, with a variable repetition rate from 90 to 4000 pulses per second to establish a repetition rate for the coincidence selector circuits.

8. <u>The Selector Pulse Multivibrators</u>

Although the multivibrator is a poor generator of fast rectangular waveforms, it does possess two desirable characteristics:

1) The duration is established by an R-C network which may be changed to provide different durations.

2) It is simple and with reasonable precautions,[17] a stable generator.

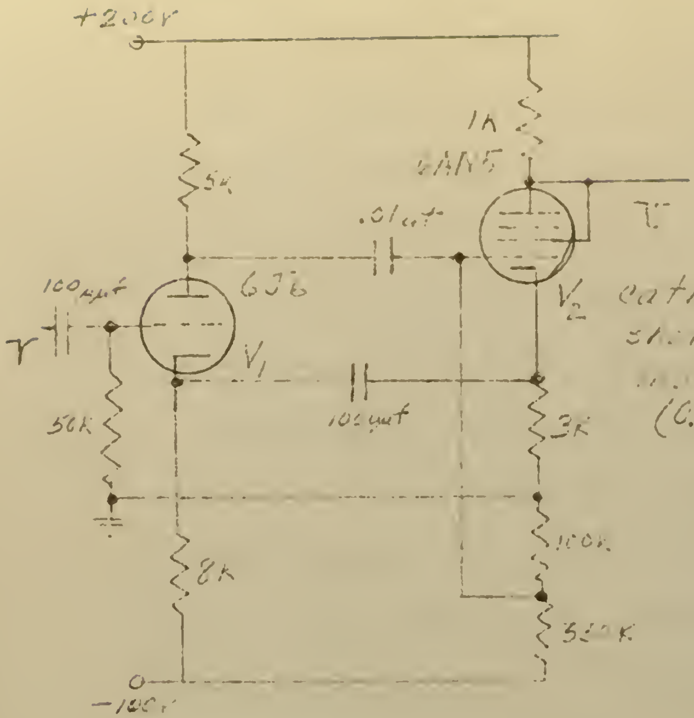
Several types of these circuits[18] have been developed for short-duration pulses. After due consideration of the possible types, attention was focused on two forms as indicated by the circuit diagram in Figure II-4.

The circuit in (a) has several advantages namely,

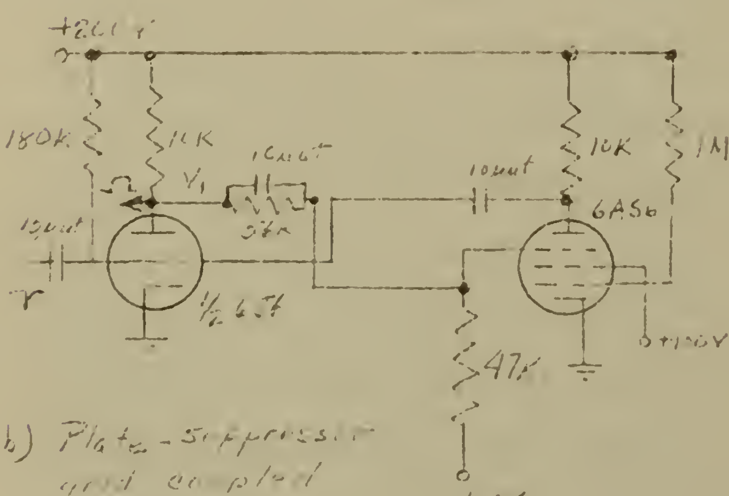
1) Direct input of the trigger may be employed without danger of reaction on the circuit.

2) Likewise, the plate circuit of the 6AN5 is free of the duration networks, and a fast negative pulse may be secured at this point.

3) The short-duration network is in the cathode circuit therefore the full tube



(a) cathode coupled short duration multivibrator (0.8us)



(b) Plate-suppressor grid coupled multivibrator (0.9us)

FIGURE II-4

currents are available to charge the stray capacitances and the timing condenser.

The circuit in (b) has one major advantage; the sharp break characteristics of the 6AS6 pentode suppressor grid gives rise to an excellent rectangular waveform which may be taken from the plate circuit of V_1.

Experimental data, has indicated that the circuit in (b) provides a satisfactory positive selector pulse for use in the coincidence circuits. This circuit is employed in a successful experimental model of the synchronizer.

9. <u>The Coincidence Circuits</u>

The two coincidence circuits used in the synchronizer are of similar design[19] with signal injection to the control grid (g_1), and selector pulse injection to the suppressor grid (g_3). They employ a 6AS6 minature type pentode developed especially for this purpose. The suppressor grid (g_3) characteristics[20] (i_p vs e_{g3}) of this tube are flat over the positive range of e_{g3} and exhibit sharp breaks at -8 volts (plate current cutoff) and at 0 volts (plate current saturation). Any positive selector pulse injected into this grid, of sufficient

amplitude to drive it positive, causes a constant plate current to flow in the positive region regardless of the shape of the top of the pulse. This is a distinct advantage over other type mixer tubes since pulses of relatively poor waveform and amplitude of 10 volts may be used to switch the tube.

In an experimental model of the coincidence circuit employed; with an input signal, e_{s1} = a 4 volt positive pulse, of 0.6 μs duration, e_{s3} = a 64 volt positive pulse of 2 μs duration, no trace of the selector pulse was observed in the output.

10. <u>The Gate Mixing and Amplifier Circuits</u>

This circuit is one of the cathode follower type[21] with all cathodes connected in parallel. Each harmonic is applied to a separate grid and the addition of the harmonics appears across the common cathode resistor. The resultant waveform is a 16 megacycle half-wave superimposed on a pyramid of 8, 4, 2, and 1 megacycle half-waves.

This waveform is impressed on the grid of a 12AT7 limiting amplifier. The input grid of this amplifier is biased below the plate current

cut-off so that it remains inoperative until a selector pulse is injected into the mixing circuit. This pulse raises the signal level above the cut-off point so that the 16 megacycle half-wave is accepted bv the amplifier. The selected 16 megacycle half-wave is limited, and amplified to serve as an intensifier pulse.

One consideration in the design of the amplifier is the possible failure of the limiting action on fast waveforms. Regardless of poor limiting action in the amplifier, the natural saturation of beam current in the cathode ray tube with positive grid excitation will limit the gate pulse amplitude. A resistor is inserted in the grid lead to the cathode ray tube to accentuate this limiting process so that a substantially level brilliance is achieved through the pulse duration.

The circuit diagrams of the complete system are illustrated in Figures II-5 and II-6. The operation of the unit may be described as follows:

1. <u>The Sweep Circuits</u>

A modified, Pierce type crystal oscillator (6AG7) generates a one megacycle timing wave which is multiplied in three cascaded, frequency

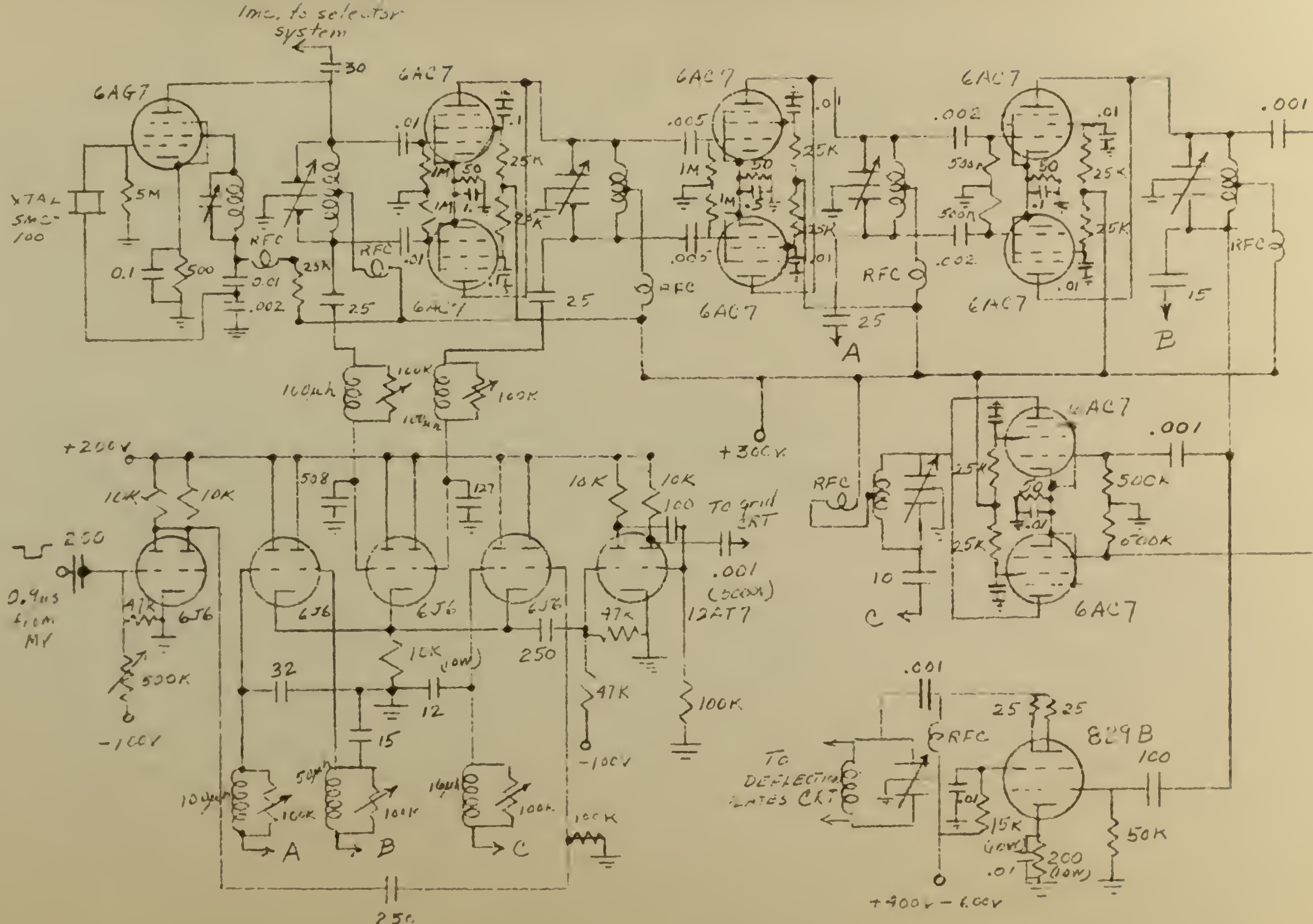
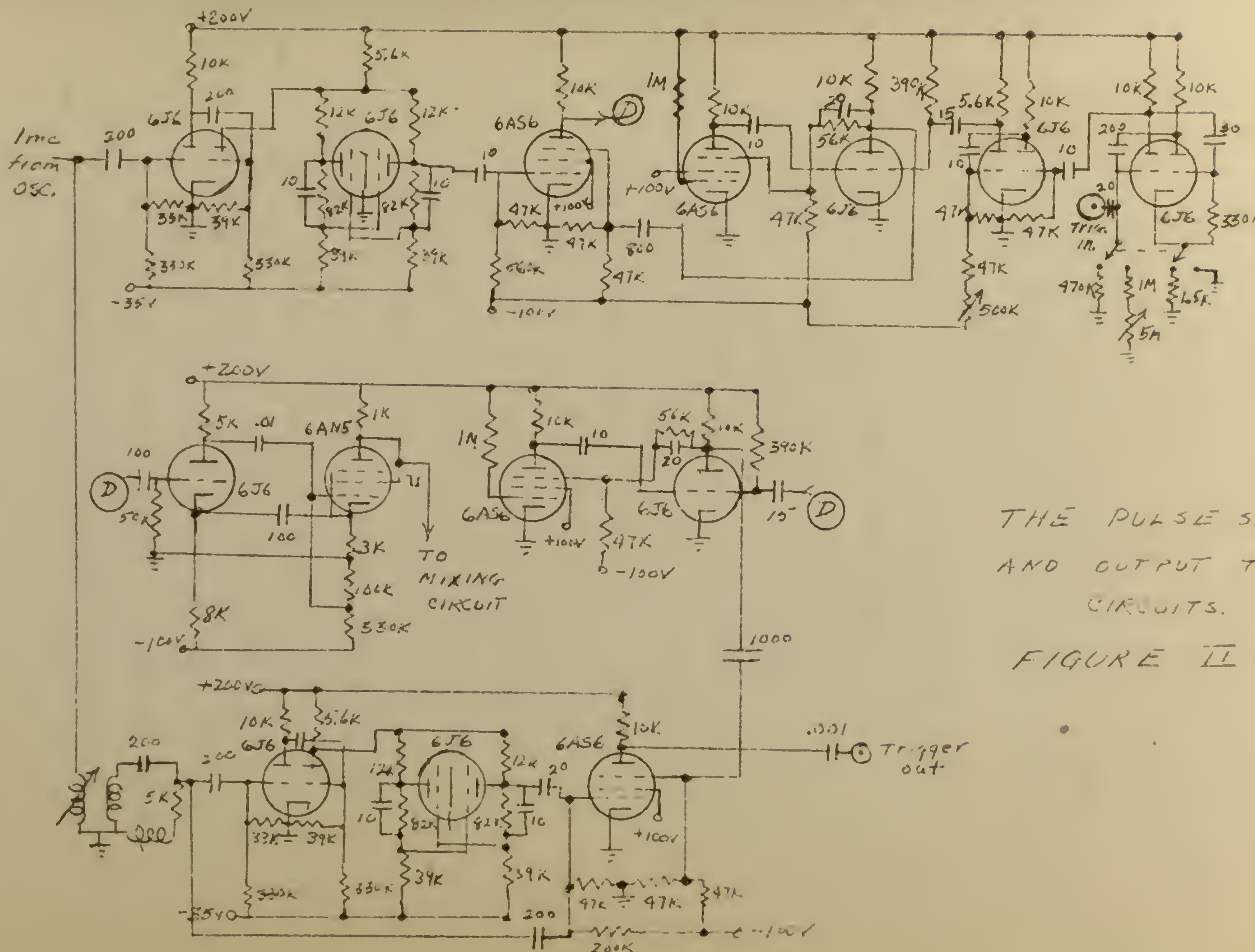


FIGURE II-5 THE SWEEP AND INTENSIFIER CIRCUITS.



THE PULSE SELECTION AND OUTPUT TRIGGER CIRCUITS.

FIGURE II -6

doubler circuits (6-6AC7) to eight (8) megacycles. The eight megacycle sinewave is amplified in a Class C power amplifier (829B) to approximately 2000-2700 volt peak to peak amplitude. The "tank" circuit of this amplifier is coupled to the deflection plates of the 5RP2A cathode ray tube to furnish the sinusoidal sweep voltage.

Since the sweep voltage is continuously applied to the deflecting plates, its repetition rate is eight million sweeps per second. In order to reduce the display sweep rate to a usable trigger rate, a gate pulse selection circuit is employed. This circuit illuminates one of the sweep cycles in accordance with a repetition rate established by a separate trigger. This trigger may be furnished either externally by equipment under test or by an incorporated astable, "Free-Running" multivibrator.

2. The Pulse Selection And Trigger Circuits

The one megacycle timing wave is introduced into a binary counter (bistable (flip-flop) circuit) through a "peaking and squaring" amplifier. The binary counter converts the one megacycle squared sine wave into a series of

one microsecond square pulses. The output of the counter is differentiated by an RC circuit, and applied to grid #1 of a type 6AS6 coincidence tube which is biased to accept only the positive peaks. The selector pulse (1.9 μs in duration) is injected into grid #3 of the coincidence tube. This selector pulse is generated as follows. A combination astable-monostable multivibrator (6J6) generates a negative 50 μs pulse at a variable repetition rate of 90 to 4000 cps. This pulse is differentiated, peaked, and amplified in a two stage amplifier (6J6). The negative trigger, thus generated, is used to actuate a monostable multivibrator (6AS6-6J6) which generates a 1.9 microsecond square positive pulse. This positive pulse is employed as the selector pulse as stated above.

The negative, one megacycle trigger selected by the selector pulse is used to trigger two monostable multivibrators, (6AS6-6J6) (6J6-6AN5) one of 0.9 μs duration and one of 2.0 μs duration. The first of these two multivibrators supplies a 0.9 μs negative gate pulse to the CRT gating circuit. The second of these two multivibrators supplies a 2.0 μs gate pulse to

grid #3 of a second coincidence tube (6AS6), on whose grid #1 is impressed the phase shifted 1 megacycle wave and the phase shifted, square 1 microsecond pulses from a binary counter (6J6). This coincidence circuit selects one of the phase shifted 1 megacycle sine waves which is used as a trigger.

3. <u>The Intensifier Pulse Circuits</u>

The intensifier pulse for the cathode ray tube is derived from a mixer of 1 mc., 2 mc., 4 mc., 8 mc., and 16 mc sine waves obtained from the oscillator and the frequency doublers in the sweep system. These waves are phase shifted 90 degrees and mixed in a common cathode type mixer (2-6J6). The output of this mixer is impressed on the grid of the gate amplifier which is biased so that this resultant wave form causes no plate current to flow. When the pulse from the 0.9 μs multivibrator is injected into the mixing circuit, it raises the voltage above the cutoff value, and allows one of the 16 megacycle positive peaks to act as an intensifier gate pulse. This is limited and amplified in the gate amplifier and applied to the grid of the cathode ray tube.

CONCLUSION

The majority of the information presented in this essay is the direct result of theoretical and experimental work conducted over a period of two years. Although substantial test work remains to be accomplished on the prototype model, no major difficulty in obtaining satisfactory circuit operation has been experienced.

It is the opinion of the author that fast sweep oscillographs designed on the principles in this essay are feasible and practical and they may be designed into light, compact forms.

REFERENCES

1. Gordon Lee; "A Three Beam Oscillograph for Recording Frequencies up to 10,000 Megacycles" Proc. I.R.E., March, 1946.
2. A.S. Zworykin; Electron Optics and The Electron Microscope.
3. Radiation Laboratory Series, Volume 22.
4. The instantaneous rate of deflection of the beam spot in tracing a waveform on the screen of the cathode ray tube. It is the resultant vector rate of the X axis deflection rate and the Y axis deflection rate and is usually expressed in inches per microsecond.
5. A Catalog of Equipment for Oscillograph Allen B. DuMont Laboratories, Inc, Pages 155 to 158.
6. Reference 5: Pages 104 and 105.
7. Radiation Laboratory Series, Vol. No. 19, Waveforms, Chapter 7.
8. For a thorough discussion of Sinusoidal Frequency Multipliers see Radiation Laboratory Series, Vol. 19, Chapter 15.
9. For a thorough discussion of Sinusoidal Frequency Dividers see Radiation Laboratory Series, Vol. 19, Chapter 15.
10. Radiation Laboratory Series, Vol. 18, "Vacuum Tube Amplifiers".
11. Basic circuit diagram furnished with Bliley SMC-100 type crystal.
12. Radiation Laboratory Series, Vol. 19, Chapter 4, Sections 4-3 and 4-5.
13. L.A. Meacham; The Bridge Stabilized Oscillator, Proc. I.R.E., October, 1938.
14. F.E. Terman; Radio Engineering, 2nd Edition, Page 340.
15. F.E. Terman; Radio Engineering, 2nd Edition, Chapter VII, Section 61.
16. Radiation Laboratory Series, Vol. 19, Chapter 5, Section 5-4.
17. Radiation Laboratory Series, Vol. 19, Chapter 5, Section 5-13.
18. Reference 17; Chapter 5, Section 5-9, 5-10.
19. Radiation Laboratory Series, Vol. 19, Chapter 10, Pages 379-382.
20. Radiation Laboratory Series, Vol. 19, Page 89.
21. Radiation Laboratory Series, Vol. 19, Chapter 18, Section 18-3.

VITA

The author was born in Chester, Pennsylvania, August 28, 1916. He was educated in the public schools of Bordentown, New Jersey and was graduated from high school in 1934. Entering the United States Naval Academy, Annapolis, Maryland in 1936, he was graduated and awarded the degree of Bachelor of Science in 1940. Periodically, during the years 1940 to 1946, he attended various professional schools in the Navy. In 1946, he was enrolled at the U. S. Naval Postgraduate School for 3 years graduate training in Ordnance Engineering. After completion of one year at the above school, he was entered at the Johns Hopkins University to complete the remaining two years of training.